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FUNGAL RESISTANCE OF NONMETALLIC HONEYCOMB CORE MATERIALS FOR SHELTER PANELS

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FINAL REPORT

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Commercial and military shelter-grade honeycomb core structure materials were evaluated to determine their resistance to biodeterioration. These materials were bio-susceptible not only to fungi, but to termites as well. Recommendations were made to lengthen their use life by addition of fungicides to kraft paper and adhesive materials, by use of inherently bioresistant materials, and by employment of approved pesticide control techniques.

(cont'd)

20. Abstract (cont'd)

As a result of these studies, (1) the specification fungal resistance test procedure was upgraded, (2) a data base for fungal resistance of military sheltergrade honeycomb was established, and (3) production honeycomb core materials were evaluated for compliance with upgraded fungal resistance requirements.

PREFACE

In support of the US Army Natick Research & Development Center (NRDC) tactical shelter program, studies were performed to characterize the microbial susceptibility of the various types of military shelter-grade, nonmetallic honeycomb and to develop an improved specification procedure for measuring the microbial deterioration of honeycomb material. This report also contains the results of studies performed to develop a data base for the microbial resistance of military shelter-grade honeycomb and to assist in the evaluation of production blocks of honeycomb core for compliance with the upgraded fungus resistance requirements of MIL-H-43964(GL). The work was performed under Program Element 6.2, Project 1L162723AH98, Work Unit CH001.

These studies were made possible by the assistance of Mr. Jack Siegel and Mr. John F. Wheeler, both representing the Aero-Mechanical Engineering Laboratory (AMEL) Tactical Shelters Branch, NRDC, who furnished honeycomb samples and technical expertise regarding honeycomb engineering. Mr. Edward J. Worrel, Construction Engineering Research Laboratory (CERL), supplied commercial shelter-grade honeycomb samples. Dr. Edward W. Ross (AMEL) performed the statistical analyses on the production blocks of honeycomb core. Mr. Carl Frenning, Individual Protection Laboratory (IPL), advised as to adhesive selection and furnished adhesives for use and evaluation. Dr. John J. Pratt, Jr., provided entomological expertise.

Other personnel from NRDC contributed to this effort. Mr. John F. Lupien (AMEL) and Mr. Joseph Moroney (AMEL) performed in-house compressive strength tests. Personnel from LeBlanc Research Corporation, N. Kingstown, RI, and Hexcel Corporation, Dublin, CA, also contributed compressive strength data. Dr. David L. Kaplan provided editorial assistance in preparation of this manuscript.

DISCLAIMER

Nonmetric terminology is used in this report to differentiate between honeycomb cores of different cell size and density in accordance with the manufacturer's designation for their products.

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INTRODUCTION

There has been a continuing effort at the US Army Natick Research & Development Center (NRDC) to develop and improve nonmetallic, phenolic resin-impregnated, honeycomb core materials designed specifically for use in construction of military rigid-wall shelters. A portion of this effort has been directed toward improving the characteristics of composite panels consisting of aluminum skin/paper honeycomb core construction. However, the longer-range approach has been to develop and evaluate composite panels made from new materials to further improve overall properties and reduce costs.

An industrial/military technical working group was formed to determine the essential characteristics of a nonmetallic honeycomb core, to develop an improved, nonmetallic honeycomb core specifically for use in military shelters, and subsequently to prepare a new military specification (MIL-SPEC) for use by core manufacturers. The new specification was to provide a resilient core that would not rupture during transport, yet would be able to sustain the loads imposed on all panels of the shelter.

Other efforts on current composite panels have been directed toward improving the structural film adhesive bond between the aluminum skin and the nonmetallic core. Studies were undertaken to screen new adhesives for high shear characteristics at elevated temperatures and for relatively high resistance to peel; currently used adhesives usually meet only one of these two requirements.

Studies were initiated to evaluate nonmetallic core honeycomb for fungal resistance in support of the Aero-Mechanical Engineering Laboratory (AMEL), NRDC tactical shelter program for military field mobile shelters. Concurrent microbial studies were performed on commercial shelter-grade honeycomb materials from Construction Engineering Research Laboratory (CERL), Champaign, IL. These materials, under consideration for use as semipermanent housing, presented an opportunity for evaluating the fungal resistance of shelter materials being considered for military construction but not fabricated to military specifications.

Preliminary studies performed on samples of military and foreign grades of resin-impregnated and nonresin-impregnated honeycomb established that paper core honeycomb from various sources was susceptible to fungus, but did not determine whether the growth was superficial or resulted in deterioration of key physical properties, such as compressive strength. Further studies were needed: (1) to develop a specification procedure that would determine the fungal resistance of honeycomb materials as a measure of actual damage to the honeycomb; (2) to establish a data base for the fungal resistance of MIL-H-43964 (GL)[1] types of honeycomb; and (3) to assist in the evaluation of production honeycomb core to determine compliance with the upgraded fungal resistance requirements of MIL-H-43964 (GL).

MATERIALS AND METHODS

Sample Preparation

Materials evaluated in these studies are listed in Table 1. Commercial materials were received from CERL and MIL-SPEC materials from AMEL Tactical Shelters Branch, NRDC. Both commercial materials were constructed with a layer of hardboard between the paper base and aluminum skin. The hardboard layer was absent from MIL-SPEC materials from NRDC.

All materials supplied were evaluated as 10 cm x 10 cm specimen blocks. The three materials supplied with aluminum skins were tested without epoxy adhesive stabilization. The others, except for Study 3 materials tested at Hexcel Corp., were stabilized with epoxy adhesive to minimize localized end failure during compressive strength testing. The adhesive used was 3M Scotch-Weld* 1838 B/A Structural Adhesive.[2]

Test Methods

Compressive strength measurements were performed in accordance with the Core Compression Method of MIL-STD-401B[3] [ASTM Method C365-57 (Reapproved 1980)].[4]

The fungal susceptibility test methods performed were:

(1) Soil burial exposure by Method 5762 of Federal Test Method Standard 191A;[5]

(2) Tropical chamber exposure by Method 508.1 of MIL-STD-810C;[6]

(3) Humidity chamber (100% RH) exposure after spraying with ASTM spore mixture from ASTM Method G21-70 (Reapproved 1980);[7]

(4) Plate tests by ASTM Method G21-70, (Reapproved 1980).

RESULTS

Development of Fungal Resistance Test

The first comparative study on fungal resistance test methods included both commercial and MIL-SPEC honeycomb core materials. Connell and Endure honeycomb samples from CERL were aluminum skinned (closed core), commercial, non MIL-SPEC materials fabricated with an inner hardboard layer. The remaining materials were MIL-SPEC items, without a hardboard layer, supplied by AMEL. Honeycomb material designated "AMEL" also was aluminum skinned, but Hexcel and Parcore samples were open core; that is, without an aluminum skin.

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*Scotch-Weld is a registered trade name of the 3M company. Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

Both CERL materials were very susceptible in plate tests and tropical chamber exposure after 1 month. Both the paper and hardboard supported extensive fungal growth. Figures 1 and 2 show the appearance of CERL materials after 2 1/2 months of exposure in plate tests. The CERL materials delaminated in plate tests or when exposed in a small chamber saturated with water vapor; the adhesive actually lifted up from the surface. There were also indications of separation in tropical chamber exposed material.

TABLE 1. Honeycomb Core Materials.

Study	Designation	Base	Cell size, cm	Density, kg/m^3 nominal average	Density, kg/m^3 actual average	Tested with aluminum skin
I	Commercial					
	Connell[a]	paper	1.27	--		Yes
	Endure[b]	paper	1.90	--		Yes
	MIL-SPEC					
	AMEL[c]	paper		61		Yes
	Hexcel[c]	paper		61		No
	Parcore[c]	paper		61		No
II	Hexcel HRH 10 1/4-3.0	Nomex	0.64	48		No
	Hexcel Nomex 1/4-3.0	Nomex	0.64	48		No
	Hexcel WRII 3/8-3.8	paper	0.95	61		No
	Parcore WRII 3/8-3.8	paper	0.95	61		No
	Hexcel WRII 3/8-2.5	paper	0.95	40		No
III	Hexcel WRII 3/8-3.8					
	block #1	paper	0.95	61	58.3	No
	#2	paper	0.95	61	63.9	No
	#3	paper	0.95	61	56.7	No
	#4	paper	0.95	61	65.5	No
	#5	paper	0.95	61	62.8	No
	Hexcel WRII 3/8-2.5					
	block #6	paper	0.95	40	41.5	No
	#7	paper	0.95	40	41.7	No
	#8	paper	0.95	40	42.9	No
	#9	paper	0.95	40	42.5	No
	#10	paper	0.95	40	42.5	No

[a]Reported to have 1/2 in cell size.
[b]Reported to have 3/4 in cell size.
[c]Reported to have 3/8 in cell size and 3.8 lb/ft^3 density.

Figure 1. Endure panel after $2\frac{1}{2}$ months of incubation.

Figure 2. Connell panel after $2\frac{1}{2}$ months of incubation.

Further evidence of adhesional problems in honeycomb materials surfaced with an emergency requirement for adhesive field repair kits for MIL-SPEC honeycomb shelter construction. As a result, different adhesives were evaluated by the Adhesives Laboratory, Individual Protection Laboratory (IPL), NRDC, for effectiveness in honeycomb composite materials construction. Five epoxy adhesives were submitted by the Adhesives Laboratory for microbial testing, and all five were fungal-resistant in tropical chamber and plate tests.

In comparison with the CERL materials, AMEL MIL-SPEC honeycomb materials were about 10 times stronger and supported only light growth (Fig. 3).

Figure 3. **AMEL shelter-grade honeycomb after 7 weeks of incubation.**

Parcore honeycomb, a newer, more flexible MIL-SPEC material, was much more susceptible to fungal growth in plate tests than Hexcel. The adhesives were highly susceptible to fungal growth, and Parcore adhesives were much more susceptible than Hexcel adhesives.

Table 2 contains comparative data between tropical chamber and soil burial exposure for commercial and MIL-SPEC honeycomb materials. Connell and Endure materials retained 68% and 58% compressive strength, respectively, after 21 days of soil burial, whereas the three MIL-SPEC materials ranged between 83% to 87% strength retention for the same length of exposure. With

TABLE 2. Compressive Strength Data From Open and Closed Core[a] Honeycomb Materials After Microbial Exposure.

	Closed Core									Open Core					
	Connell[b]			Endure[b]			AMEL[c]			Hexcel[c]			Parcore[c]		
Microbial Exposure (days)	$\bar{x}$ (MPa)[d]	s[e] (MPa)	% ret	$\bar{x}$ (MPa)	s (MPa)	% ret	$\bar{x}$ (MPa)	s (MPa)	% ret	$\bar{x}$ (MPa)	s (MPa)	% ret	$\bar{x}$ (MPa)	s (MPa)	% ret
Tropical Chamber															
0	0.434	0.004	-	0.407	0.053	-	3.40	0.112	-	3.76	0.140	-	3.43	0.335	-
28	-	-	-	-	-	-	-	-	-	3.25	.211	86	2.79	.418	81
42	-	-	-	-	-	-	2.81	.099	83	-	-	-	-	-	-
90	.318	.026	73	.287	.050	71	2.90	.129	85	3.37	.145	90	2.81	.187	82
180	.277	.059	64	.279	.064	69	3.18	.053	94	3.25	.116	86	3.08	.328	89
360	.295	.028	68	.251	.078	62	3.27	.261	96	3.01	.135	80	1.74	.234	51
720	.251	.051	58	.179	.028	44	-	-	-	-	-	-	-	-	-
Soil Burial															
0	.434	.004	-	.407	.053	-	3.40	.112	-	3.76	.140	-	3.43	.335	-
4	-	-	-	.328	.046	81	3.06	.110	90	-	-	-	-	-	-
7	.324	.014	75	.328	.024	81	3.08	.124	91	3.24	.201	86	2.90	.215	85
10	-	-	-	.293	.047	72	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	3.23	.157	86	2.85	.147	83
21	.296	.007	68	.238	.058	58	2.90	.157	85	3.28	.084	87	2.85	.313	83
28	-	-	-	-	-	-	-	-	-	3.05	.098	81	2.72	.261	79
35	.317	.018	73	.193	.060	47	-	-	-	3.07	.196	82	2.34	.440	68
42	-	-	-	-	-	-	2.62	.066	77	3.14	.131	84	2.23	.247	65
77	.248	.033	57	.257	.028	63	2.91	.180	86	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-	3.37	.168	90	2.19	.391	64
180	-	-	-	-	-	-	2.99	.162	88	2.84	.329	76	2.39	.188	70

[a]Open and closed core refers to absence and presence, respectively, of aluminum skin.
[b]Nonspecification items.
[c]Specification items supplied by Tactical Shelters Branch, AMEL, NRDC.
[d]MPa = $(lb/in^2)(6.895 \times 10^{-3})$.
[e]One standard deviation.

continued exposure, Parcore honeycomb lost strength faster than AMEL or Hexcel. Similar results relative to fungal susceptibilities of commercial and MIL-SPEC honeycomb materials are apparent in the tropical chamber data. However, it took longer for the fungal susceptibilities of the honeycomb materials to be evident in tropical chamber exposure than in soil burial exposure.

Data Base for Fungal Resistance of MIL-H-43964 (GL) Honeycomb

The two major suppliers of military shelter-grade honeycomb, Parsons of California (Stockton, CA) and Hexcel Corporation (Dublin, CA), submitted for evaluation, in soil burial, core types specified in MIL-H-43964 (GL) -- the newly developed MIL-SPEC for honeycomb core, nonmetallic, shelter panels. MIL-H-43964 (GL) designates soil burial for 28 days as the new fungal resistance test. To evaluate the adequacy of the new fungal resistance test, this study was undertaken to develop data for additional types of MIL-SPEC honeycomb.

The five honeycomb core types received for evaluation fit into the three categories of high and medium strength honeycomb cores designated in MIL-H-43964 (GL). Three were manufactured from WRII kraft paper and two from Nomex(R)* nylon paper base.

In plate testing after 1 week of incubation, Parcore honeycomb supported moderate to heavy fungal growth, whereas both Hexcel kraft varieties supported light to moderate growth, particularly along cut edges and on the adhesive. One Nomex honeycomb did not support fungal growth, but the other supported light fungal growth attributed to surface contamination.

Extra specimens not needed for soil burial were exposed in the tropical chamber for resistance to fungal growth. There were not enough specimens to evaluate Parcore honeycomb, but of the others, Hexcel kraft varieties supported light to medium growth after 1 year of tropical chamber exposure, whereas Nomex varieties did not support growth.

Table 3 contains soil burial data obtained from honeycomb core conforming to types specified in MIL-H-43964(GL). All specimens were evaluated as open core. The data through 5 weeks of soil burial are consistent with the data in Table 2. Data from extended soil burial indicate that both Parcore and Hexcel materials retain 61% through 64% compressive strength after 12 weeks of exposure. The 26- and 52-week data are not consistent with earlier soil burial data for Parcore and Hexcel kraft core honeycomb. HRH 10 and Nomex, both Nomex core honeycombs, did not deteriorate in soil burial exposure.

*Nomex is a registered trade name of E.I. du Pont de Nemours & Co., Inc. Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

TABLE 3. Compressive Strength Data From MIL-H-43964 (GL) Nonmetallic Honeycomb Core Materials After Soil Burial Exposure.

Soil Burial (weeks)	Hexcel HRH 10 1/4-3.0			Hexcel Nomex 1/4-3.0			Hexcel WRII 3/8-3.8			Parcore WRII 3/8-3.8			Hexcel WRII 3/8-2.5		
	$\bar{x}$ (MPa)[a]	s^b (MPa)	% ret	$\bar{x}$ (MPa)	s (MPa)	% ret	$\bar{x}$ (MPa)	s (MPa)	% ret	$\bar{x}$ (MPa)	s (MPa)	% ret	$\bar{x}$ (MPa)	s (MPa)	% ret
0	3.19	0.24	-	2.07	0.29	-	2.93	0.10	-	3.19	0.70	-	1.63	0.14	-
1	-	-	-	-	-	-	2.71	.13	92	2.85	.40	89	1.44	.10	88
2	-	-	-	-	-	-	2.82	.14	96	2.75	.61	86	1.45	.07	89
3	-	-	-	-	-	-	2.59	.16	88	2.63	.53	82	1.33	.16	82
4	-	-	-	-	-	-	2.56	.30	87	2.29	.34	72	1.34	.09	82
5	-	-	-	-	-	-	2.40	.33	82	2.25	.26	71	1.31	.14	80
6	-	-	-	-	-	-	2.52	.20	86	2.46	.53	77	1.35	.09	83
7	-	-	-	-	-	-	2.16	.30	74	2.18	.33	68	1.29	.15	79
8	-	-	-	-	-	-	2.15	.26	73	2.13	.49	67	1.35	.14	83
9	-	-	-	-	-	-	1.82	.16	62	2.36	.51	74	1.09	.12	67
10	-	-	-	-	-	-	2.00	.22	68	2.06	.44	65	1.06	.08	65
11	-	-	-	-	-	-	1.82	.15	62	1.98	.43	62	1.02	.13	63
12	3.39	.16	106	2.05	.22	99	1.78	.21	61	1.99	.53	62	1.04	.12	64
26	3.34	.33	105	2.19	.20	106	2.81	.18	96	2.33	.95	73	1.40	.18	86
52	3.68	.45	115	2.40	.15	116	2.58	.34	88	3.53	.21	111	1.24	.17	76

[a] MPA = (lb/in^2) (6.895 x 10^{-3}).
[b] One standard deviation.

Evaluation of Production Honeycomb for Compliance With Fungal Resistance Requirement of MIL-H-43964 (GL)

To determine whether or not production honeycomb core was meeting the upgraded mechanical, physical, and biological requirements of MIL-H-43964 (GL), studies were initiated by AMEL to evaluate two MIL-SPEC core materials, WRII 3/8 - 3.8 and WRII 3/8 - 2.5 for compliance with the specification. Five different production blocks of both materials were evaluated to generate the engineering data required. To develop fungal resistance data, six specimens of each production block were subjected to soil burial for one exposure period of 28 days. (Compressive measurements for this study were determined by Hexcel Corporation, the contractor for this study).

Table 4 contains the compressive strength data after soil burial. Block numbers 1 through 5 designate 3.8 lb/ft^3 (pcf) core material, and 5 through 10 designate 2.5 pcf materials. Overall, the 3.8 pcf core material retained 84% compressive strength, and the 2.5 pcf core retained 92% strength after soil burial for 28 days.

MIL-H-43964 (GL) designates 85% strength retention as the minimum acceptable strength after 28 days of soil burial. Since the 3.8 pcf core material failed overall by a narrow 1% margin and the data were spread over a broad range, there was doubt that data obtained from the soil burial group were different from data obtained from the control group.

The data in Table 4 were submitted for mathematical analysis. Mathematical techniques used were bivariate plots, t tests, and orthogonal polynomials. From these techniques it was concluded that:

(1) 3.8 pcf density core was different from 2.5 pcf density core, and that, for control tests, groups within each type of material were not all the same;

(2) for 3.8 pcf density control blocks #1 through 5 at least three different groups are present (#1,3; #2,5; #4), and for 2.5 pcf density control blocks #6 through 10 all are the same except for #7;

(3) relationship between compressive strength and density can be expressed as

for control groups

$X = -268 + 193d$ where: X = compressive strength in psi

for burial groups

$X = -154 + 143d$ where: d = density in pcf

(4) for each block except #10, the control group differs from the soil burial group.

TABLE 4. Compressive Strength Data From Five Production Blocks of Two MIL-SPEC Honeycomb Core Materials After Soil Burial Exposure (28 Days).

Designation	Block Number	Average Density	Control Specimens		Soil Burial Specimens		Percent Strength Retention	Overall Percent Strength Retention
		kg/m^3	$\bar{X}$ (MPa)[a]	S^b(MPa)	$\bar{X}$ (MPa)	S (MPa)		
Hexcel WRII	1	58.3	3.05	0.12	2.76	0.04	90	
	2	63.9	3.29	.14	2.72	.05	83	
3/8-3.8	3	56.7	2.95	.14	2.45	.04	83	84
	4	65.5	3.63	.11	2.94	.07	81	
	5	62.8	3.36	.10	2.74	.06	82	
Hexcel WRII	6	41.5	1.70	.03	1.57	.04	92	
	7	41.7	1.42	.11	1.30	.05	92	
3/8-2.5	8	42.9	1.73	.07	1.54	.02	89	92
	9	42.5	1.64	.04	1.48	.07	90	
	10	42.5	1.71	.12	1.65	.10	96	

[a]MPa = $(lb/in^2)(6.895 \times 10^{-3})$.
[b]One standard deviation.

DISCUSSION

Military Specification MIL-H-21040C,[8] which was replaced by MIL-H-43964(GL) as the MIL-SPEC for nonmetallic honeycomb core for shelter panels, specifies fungal resistance testing in accordance with Method 508 of MIL-STD-810 for 28 days at 30°C after inoculation with five test organisms. MIL-H-21040C requires that after microbial exposure, compressive strength of the honeycomb material should meet or exceed prescribed graphical strength values dependent on the density of the core.

Preliminary studies indicated that MIL-SPEC honeycomb, fabricated from 4 pcf density Hexcel WR-II paper, in conformance with MIL-H-21040C, was resistant to fungal growth in tropical chamber exposure and lost no compressive strength after 110 days of exposure, despite susceptibility to fungal growth in plate tests.

It was suggested that Method 508 be improved by including the wood-rotting fungi *Gloeophyllum trabeum*, *Poria placenta* and *Trametes versicolor* as replacements for organisms specified in Method 508. The primary advantage to be gained from addition of wood-rotting fungi to Method 508 would be the capability of accelerating breakdown of wood, which has a much more complex physicochemical structure than cellulose. Since the honeycomb core specification governs the performance of a cellulosic composite material rather than a wooden material, inclusion of such organisms was not believed to be warranted.

Extensive effort has been expended on the selection of organisms suitable for Method 508. Organisms specified in Method 508 are representative of the spectrum of degradative fungi and include cellulose degraders. In fact, *Chaetomium globosum* was specifically added to the list of fungi because of its efficiency as a cellulose degrader. Experience indicates that the organisms currently specified more than adequately degrade the honeycomb material if it is not protected.

Despite satisfaction with the organisms specified in Method 508, it was the position of this laboratory that the tropical chamber test is not suitable for evaluation of honeycomb core material. Method 508 was developed for the evaluation of electronic equipment and other systems, not materials per se; it is slow to cause degradative changes sufficient to differentiate between fungus-resistant and non-resistant, resin-treated honeycomb core. The ASTM G21-70 plate test, another fungal resistance test, is primarily useful for either proving or disproving the ability of a test material to support fungal growth and is unsuitable for determining damage in structural materials.

We recommended the soil burial test procedure over the other two fungal resistance tests. Its advantages include low cost, ease of testing, and suitability for generation of meaningful deterioration test data within a time-frame short enough to be suitable for inclusion in a specification test procedure. Soil burial for 28 days was adopted as the interim fungal resistance test for MIL-H-43964 (GL) pending accumulation of additional fungal resistance data sufficient for a final recommendation.

Results from the first soil burial study (Table 2) served to confirm our soil burial recommendation. The CERL commercial materials deteriorated readily within 28 days of soil burial. Soil burial exposure for 28 days produced about the same amount of degradation in CERL honeycomb materials as produced by 360 days of tropical chamber exposure. The more resistant AMEL MIL-SPEC honeycomb materials deteriorated less readily, and there was no difference at 28 days of exposure between open core materials exposed in tropical chamber or soil burial exposure. However, 35 days of soil burial exposure was sufficient to differentiate between MIL-SPEC open core materials -- differentiation not apparent in tropical chamber results prior to 360 days of exposure.

The fungal resistance of the MIL-SPEC honeycomb materials compared to CERL materials should be further considered as to whether the materials were tested as open or closed core. In this regard, it is apparent that CERL materials, even though they were tested as closed core materials, which could not be filled with soil, were relatively biodegradable as contrasted to AMEL MIL-SPEC materials, which were more resistant even when tested open core.

In order to develop more empirical data regarding the minimal soil exposure time required to determine the fungal resistance of structural honeycomb, additional samples conforming to MIL-H-43964 (GL) core types were evaluated in soil burial. Results of the second soil burial study (Table 3) confirmed that 4 to 5 weeks of soil burial is sufficient exposure time to differentiate between varying degrees of fungal resistance in MIL-SPEC honeycomb core materials. Although Hexcel honeycomb is more resistant than Parcore at 4 to 5 weeks of exposure, the data indicate that all paper core honeycomb materials lost nearly 40% strength after 12 weeks of soil burial and therefore should be regarded as biodegradable materials, unlike inherently resistant Nomex(R) nylon core materials.

Production blocks of honeycomb core, under contractual evaluation for compliance with the upgraded requirements of MIL-H-43964 (GL), were tested in the third soil burial study. In this study the 3.8 pcf density core honeycomb failed to meet the fungal resistance requirement of not exceeding 15% compressive strength loss after 28 days of soil burial. Statistical analyses, indicating that control blocks of this material were different, suggested quality control problems in production. The 2.5 pcf density core honeycomb, which passed the fungal resistance test, showed less disparity between control blocks. It has been our observation from past studies with resin-treated, biodegradable materials that the soil burial test can be used as a measure of quality control in that materials unevenly prepared are prone to a higher failure rate. Soil burial data from production blocks of honeycomb core confirm this observation.

Based on 15% strength loss as the criterion for pass/fail after 28 days of soil burial, many of the MIL-SPEC honeycomb samples evaluated in these studies would fail. As detailed above, data indicated a quality control problem. Other cases exceeding 15% strength loss can not be similarly diagnosed due to insufficient data. However, upgrading the quality of MIL-SPEC honeycomb and improving quality control in production should enable most honeycomb samples to pass the 28 day soil burial test. The soil burial data indicate that reducing the 28 day test to a 14 day test to enable more samples to pass would not sufficiently differentiate between standard grade and marginal honeycomb manufactured to military specifications.

The field deployment of MIL-SPEC honeycomb core shelter panels fabricated with inferior adhesives resulted in a request for the NRDC Adhesives Laboratory to develop adhesive field repair kits for honeycomb core panels. Polyvinyl acetate (PVA), reported to be the bonding agent between aluminum skin and honeycomb core, was believed responsible for the field problems. Five epoxy adhesives considered for use in field repair kits were all fungal-resistant.

Other evidence of adhesive problems arose while evaluating honeycomb core samples for fungal resistance. The CERL commercial honeycomb materials delaminated in moisture-saturated environments. Either fault -- ease of adhesive delamination or ease of biodegradability should be sufficient to recommend against the projected usage of these commercial materials as semipermanent military housing. Also, the adhesives used in fabrication of MIL-SPEC Parcore and Hexcel honeycomb core, thought to be animal glues, were susceptible to fungal growth. Substitutes for these susceptible glues were not evaluated in these studies. However, a separate study performed in our laboratory on the fungal-resistance of the various classes of adhesives suggests fungal-resistant alternative adhesives.[9]

Aside from the fungal susceptibility of paper honeycomb core materials, we were equally concerned about the possibility of insect damage. Although we were unable to have supportive insect penetration studies performed on these materials, they were reported to be susceptible to termite damage in previous field trials. Also, the chance infestation of our tropical chamber by termites resulted in severe damage to MIL-SPEC honeycomb core materials (Figs. 4 and 5). This confirmed our impression that the phenolic resin treatment would be insufficient to protect these materials from insect damage.

CONCLUSIONS

In the process of upgrading the fungal resistance test method for MIL-SPEC, nonmetallic, honeycomb core materials for shelter panels, three soil burial studies were performed. The data generated in these studies supported the selection of soil burial as the new fungal resistance test method with 28 days as an appropriate exposure period. Cases where MIL-SPEC materials failed to meet the new fungal-resistance requirement were interpreted as evidence for the need to upgrade the quality of the product and/or improve quality control in production.

During the course of these studies it was shown that phenolic resin-impregnated paper honeycomb is a bio-susceptible material -- not only to fungi, but to termites as well. Whether used for semipermanent housing or mobile field units, whether field-deployed or stored, the combined biological threats should be manifested over the longer run -- particularly if accelerated by hot, moist tropical conditions.

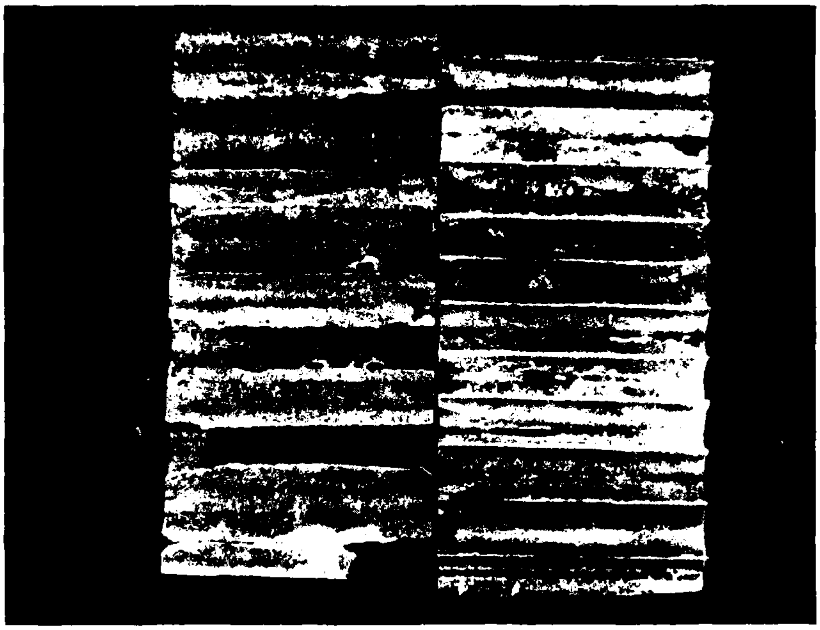

Figure 4. Edge view of AMEL shelter-grade honeycomb after termite attack.

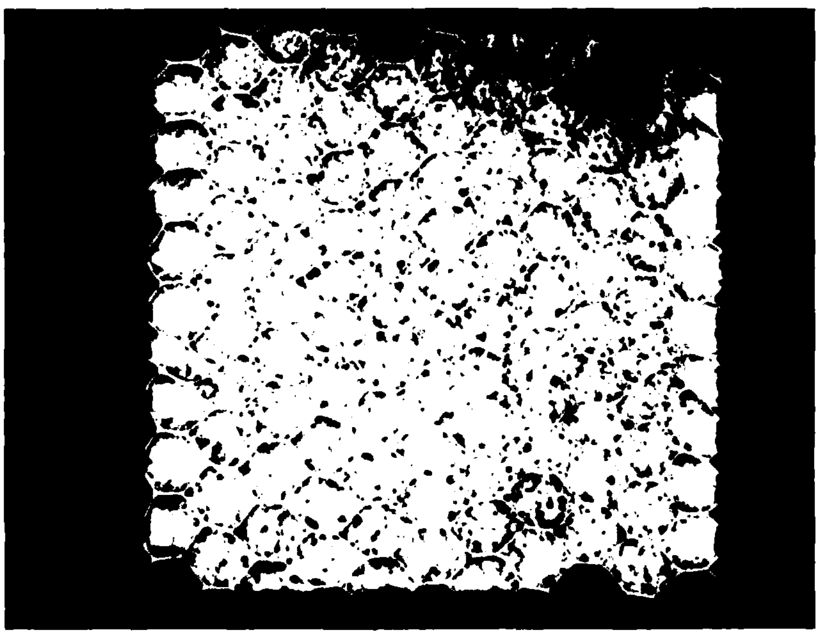

Figure 5. Front view of AMEL shelter-grade honeycomb after termite attack.

Soil burial can not be correlated with use life. Therefore, the use life of these materials can not be predicted. Since phenolic resin-impregnated paper honeycomb is a bio-susceptible material, it can not be expected to last indefinitely; therefore, it should be treated with addition of fungicides to the kraft paper and adhesives to provide maximum longevity. Other resin formulations may further improve the fungal resistance of kraft honeycomb materials. Specific recommendations for improvement of current materials must depend on the outcome of trials with biocides and other resin formulations, which were beyond the scope of these studies.

Recommendations for optimum longevity would include substitution of current bio-susceptible materials with inherently resistant Nomex nylon core and bio-resistant adhesives. With any of these materials, good conservative practice dictates approved pesticide control techniques if they are to be used for semipermanent housing in areas harboring destructive ground insects.

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